Assessing the Security of a Mission-Critical Software System

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NASA RTOP: Reducing Software Security Risk

- **NOTE:**

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Research Goal

- **Reduce security risk to the computing environment by mitigating vulnerabilities in the software development and maintenance life cycles**
  - **Vulnerability matrix**
    - **Vulnerabilities exploits and signatures**
  - **Security Assessment Tools List**
  - **Property-based testing tool—Tester's Assistant**
  - **Model-based security specification and verification tool and report**

Vulnerability Matrix

- **Vulnerability matrix to assist security experts and programmers where best to expend their efforts**
  - DOVES database (maintained by UC Davis): http://seclab.cs.ucdavis.edu/projects/DOVES
  - Uses the Common Vulnerabilities and Exposures (CVE) Listing (MITRE)
  - Contains signatures used to exploit the vulnerability – signatures to be used with the Tester's Assistant and the Modeling SPIN Tool

Security Assessment Tools

- **Software Security Assessment Instrument**
  - **Security assessment tools**
    - **Description of each tool and its purpose**
    - **Pros and Cons of each tool**
    - **Alternate and related tools**

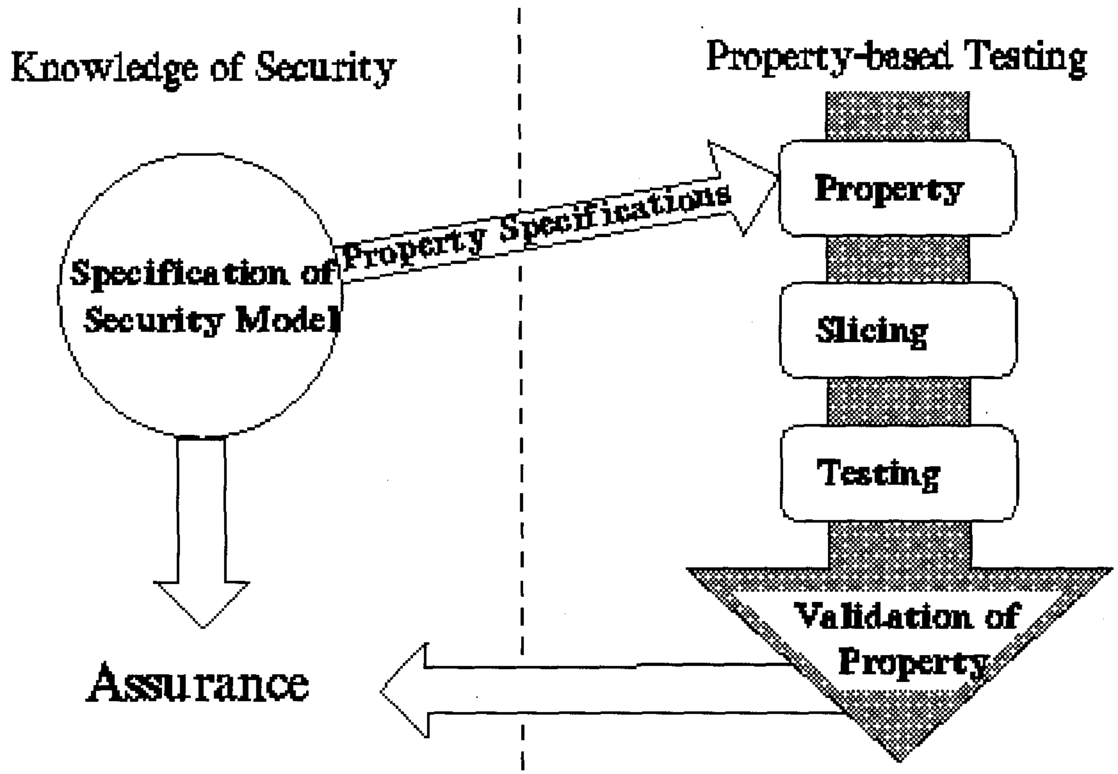
Property-Based Testing

- **Property-based testing tool – Tester's Assistant (Matt Bishop, UC Davis)**
  - ➢ **Perform code slicing on applications for a known set of vulnerabilities**
  - ➢ **Test for vulnerabilities in code on the system or whenever the computing environment changes**
  - ➢ **Initially, checks software developed in JAVA**
    - – **The goal is to have the tool check other programming and scripting languages as well (C, C++, Perl, ActiveX, etc.)**

Property-Based Testing (Cont.)

- **Compare program actions with specifications**
  - **Create low-level specifications**
  - **Instrument program to check that these hold**
  - **Run program under run-time monitor**
  - **Report violations of specifications**

Property-Based Testing (Cont.): How It Works



*Backup Slides provide an example on how this works with the TASPEC

Property-Based Tester

- **TASPEC language definitions**
  - ➢ **Handle ambiguous specifications and facts**
  - ➢ **Resetting, non-resetting temporal operators**
  - ➢ **Existential, universal logical operators**
- **Design Decisions**
  - ➢ **Instrumenter does most work**

TASpec and the TEM

- **Invariants (properties) given to TEM**
- **Test Execution Monitor accepts TASpec statements from executing program**
  - **Statements record facts about current state relevant to properties**
  - **Can *assert*, *retract* facts**
- **TEM verifies current state satisfies desired properties**

Relation to Other Spec Languages

- **Can go from Z to TASpec**
  - **Not everything translates**
  - **TASpec has no notion of type, Z does**
  - **Translation straightforward, in the sense of known algorithms**
- **Differences limit translation**
  - **Z high-level, not concerned with implementation details**
  - **TASpec low-level, lots of implementation details**
  - **Z *a priori* specification**
  - **TASpec *a posteriori* specification**

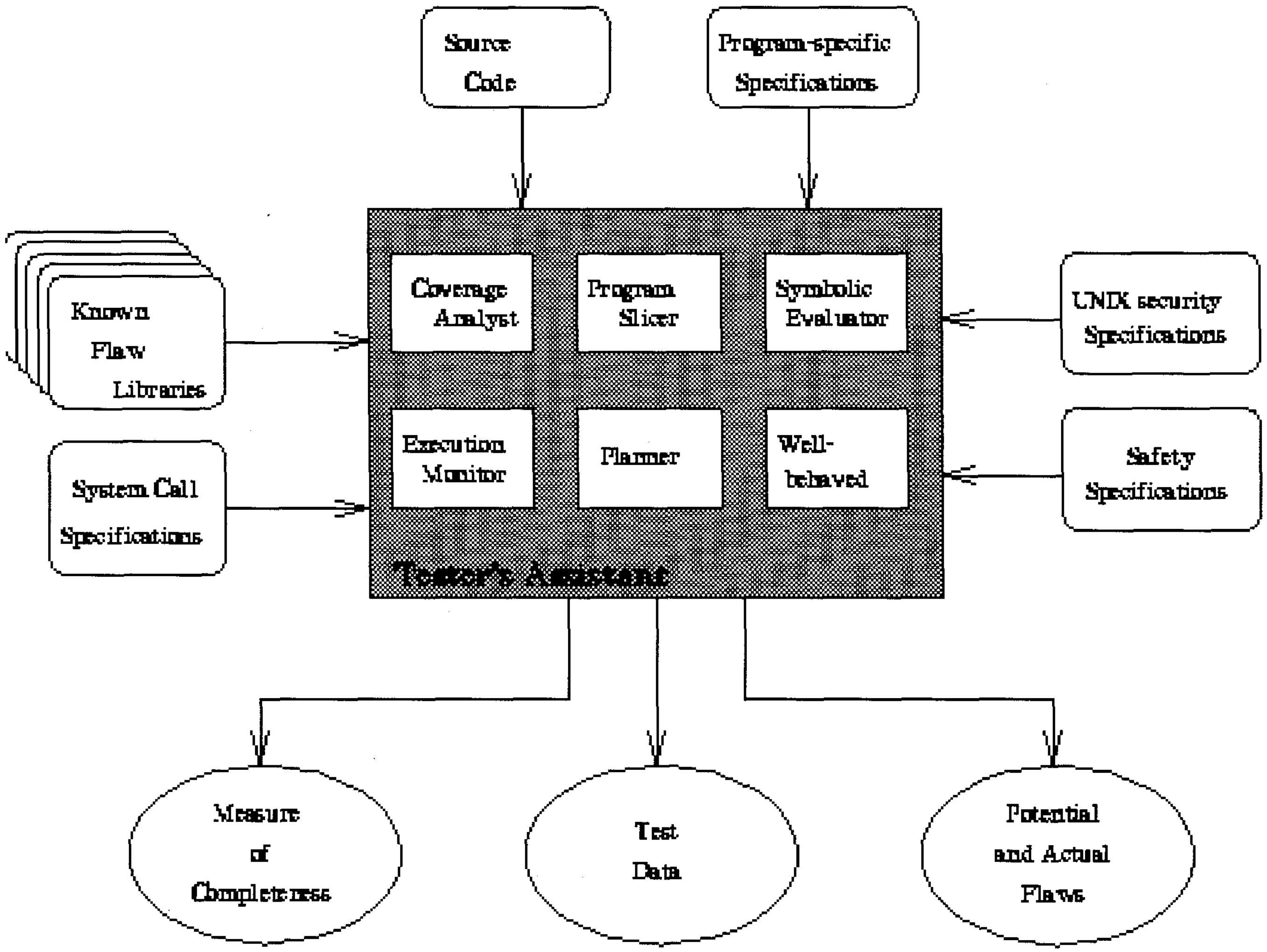
TASpec Languages

- Predicates
- Arithmetic operators: + – * / %
- Relational operators: == != > < >= <=
- Logical operators: and or not implies
  - and, or existential; not, implies universal
- Temporal operators: before until eventually
- Location specifiers: func variable decl
- Miscellaneous
  - assert, assertonce, retract, check
  - exec, forall

Complications

- **Logical operators: existential or universal?**
  - **and, or existential**
  - **not, implies universal**
- **Temporal operators**
  - ***a* before *b*: when *b* becomes true, *a* is true**
  - ***a* until *b*: from the time this property is entered, *a* is true until *b* becomes true, at which point *a* must be false**
  - **eventually *a*: *a* is true when the program terminates**

Property-Based Tester



Tester's Assistant Specifications

- **Example: "a user must authenticate himself or herself before acquiring privileges"**

```
is password correct? {
    Compare user's password hash to hash stored for that user name
    If match, set UID to user's uid
    If no match, set UID to ERROR
}
if privileges granted {
    compare UID to the uid for which privileges are granted
    if match, all is well
    if no match, specification violated
}
```

Example C Code

```
if (fgets(stdin, uname, sizeof(uname)-1) == NULL)
    return(FAILED);
typedpwd = getpass("Password: ");
if ((pw = getpwnam(uname)) != NULL){
    hashtp = crypt(pw->pw_passwd, typedpwd);
    if (strcmp(pw->pw_passwd, hashtp) == 0){
        setuid(pw->pw_uid);
        return(SUCCESS);
    }
}
return(FAILED);
```

In TASPEC

```
location func setuid(uid) result 1
    { assert privileges_acquired(uid); }
location func crypt(password,salt) result encryptpwd
    { assert password_entered(encryptpwd); }
location func getpwnam(name) result pwent
    { assert user_password(name, pwent->pw_passwd, pwent->pw_uid); }
location func strcmp(s1, s2) result 0
    { assert equals(s1, s2); }
password_entered(pwd1) and
                user_password(name, pwd2, uid) and equal(pwd1, pwd2)
    { assert authenticated(uid) ; }
authenticated(uid) before privileges_acquired(uid)
```

Merging

```
if (fgets(stdin, uname, sizeof(uname)-1) == NULL)
    return(FAILED);
typedpwd = getpass("Password: ");
if ((pw = getpwnam(uname)) != NULL){
    hashtp = crypt(pw->pw_passwd, typedpwd);
    if (strcmp(pw->pw_passwd, hashtp) == 0){
        setuid(pw->pw_uid);
        return(SUCCESS);
    }
}
return(FAILED);
```

user_password(uname, pw->pw_passwd, pw->pw_uid)

user_password(uname, pw->pw_passwd, pw->pw_uid)
password_entered(hashtp)

user_password(uname, pw->pw_passwd, pw->pw_uid)
password_entered(hashtp)
equals(pw->pw_passwd, hashtp)
authenticated(pw_>pw_uid)

Model-Based Security Specification

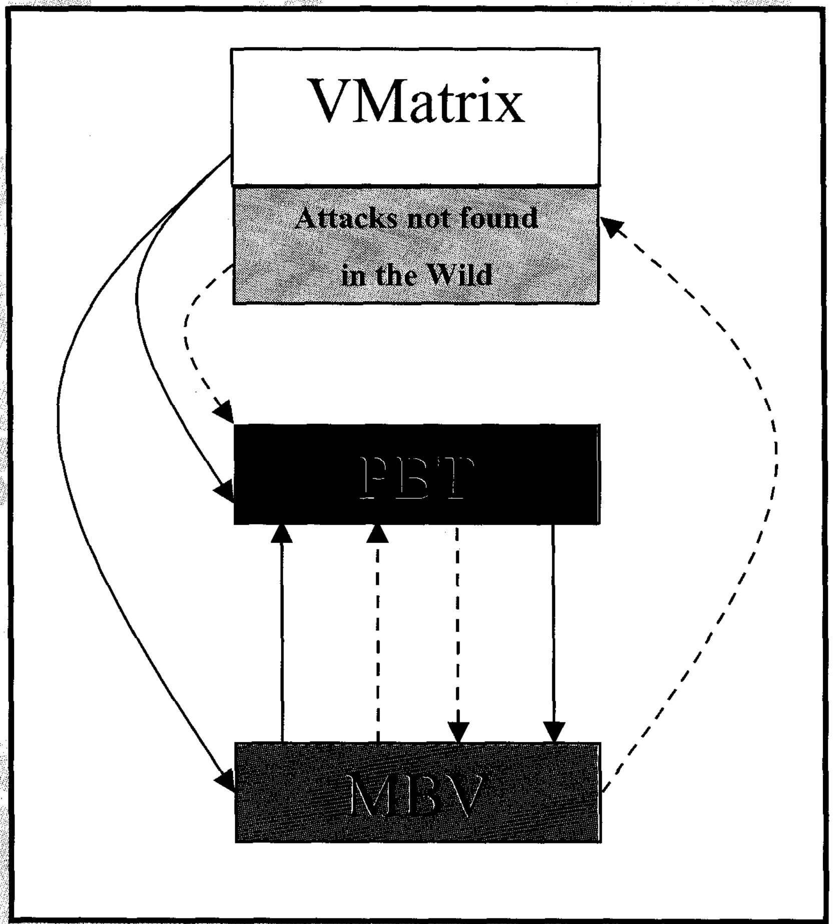
- **Model-based security specification and verification involves applying formal modeling to the IT security arena**
- **Verification systems that perform logical verification of temporal properties over models are referred to as <u>model checkers</u>**
  - **Exhaustive search of a model's corresponding state space**
  - **Can be used on suitably restricted "partial specifications"**

State Charts

- **State Charts are specification notations to define systems**
  - **Defines the collection of (abstract) variable value pairs at a given point in the system (execution) – referred to as a state**
  - **Defines the relationships with which the system transitions from one state to the another**

Model Based Verification (MBV) within an Integrated Approach

- **Flexible Modeling Framework (FMF)**
  - Compositional Approach
  - Makes use of SPIN
  - Infers Results from a partial model
- **Property Interaction with**
  - Vulnerability (VMatrix)
  - Property Based Testing (PBT)
- **Potentially discovers new vulnerabilities**



The Flexible Modeling Framework (FMF) Approach to MBV

- A Component (c) is some logical unit of process or application behavior
  - A single application often will need to be broken into multiple model components
- Combining two components C1 and C2
  - Model Checking (MC)
    1. Non-trivial combination of C1 and C2
    2. Searches the Cartesian Product of the sizes of C1 and C2
  - FMF
    1. MC of C1 and C2 individually
    2. Combines the State Charts (SC) of C1 and C2
    3. Integrates assumptions that follow from 1 above
    4. SC traversal or *localized* MC of appropriate sub-model

Domain Specifics and FMF

C1

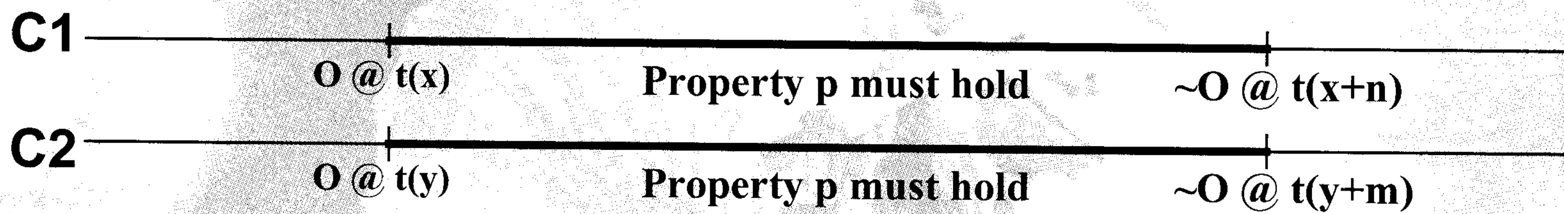
O @ t(x) Property p must hold ~O @ t(x+n)

C2

O @ t(y) Property p must hold ~O @ t(y+m)

- MC reports p holds for C1 and C2
  - Assumptions can be made about transitions (T) in C1/C2 SC
    - P holds on T from C1 ^ C2
    - P holds on T from C1 ^ (Unknown in C2)
    - P holds on T from (Unknown in C1) ^ C
- Unify consistent states in the SCs of C1 and C2
  - Condition: All variables that are known in C1 and C2 agree
- Any path from "O" that does not reach "~O" produces an unknown security result when the combined C1/C2

Combinatorial Network Aware Cases being Addressed



Network Aware (NA) Cases:

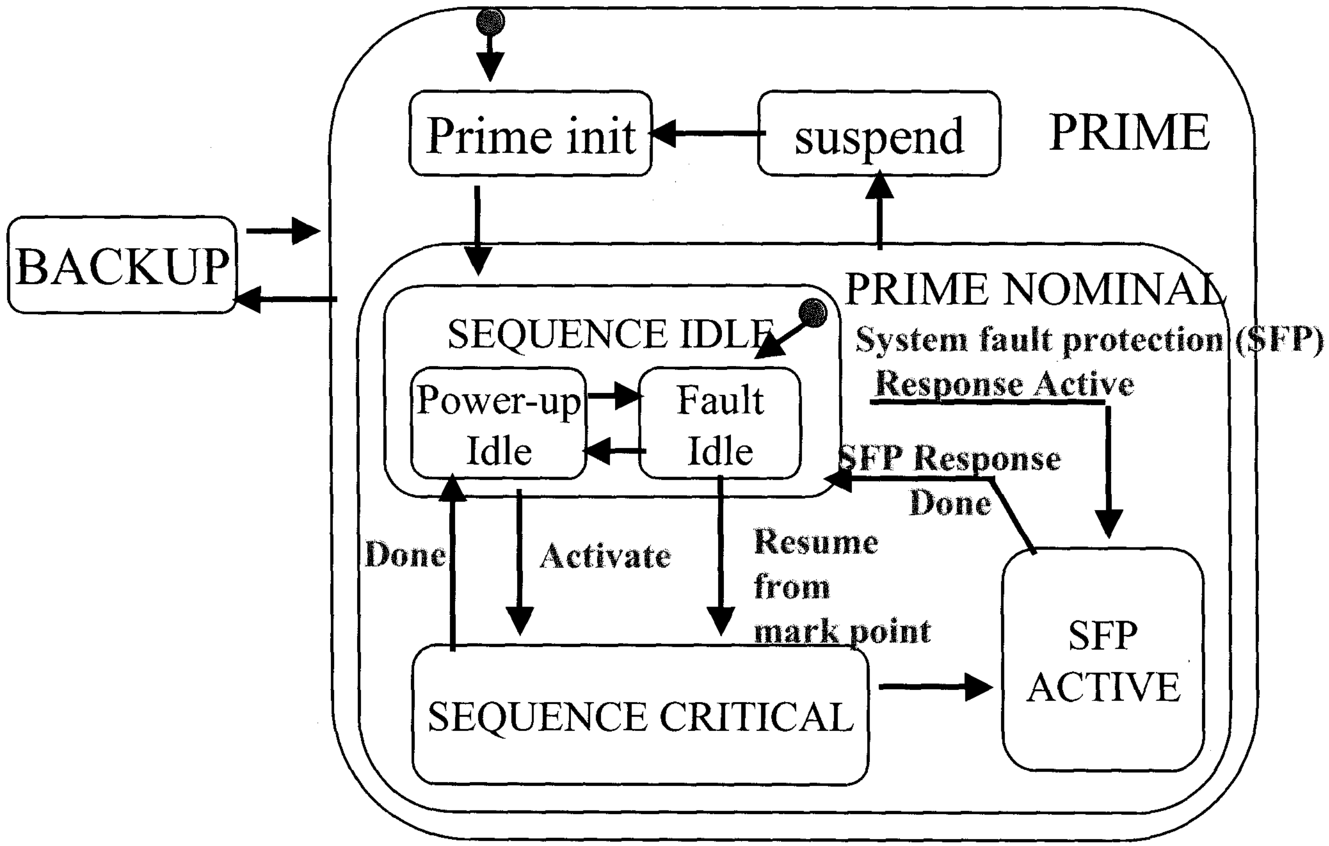
1. t(x) = t(y) – C1 and C2 are NA simultaneously
2. t(x+n) = t(y) – C1 ends NA sequence and C2 starts NA sequence simultaneously
3. t(x) = t(y+m) – C2 ends NA sequence and C1 starts NA sequence simultaneously

* Sub cases where (n = m) and (n != m) – not currently known if this distinction is significant with an abstract model in this domain

Combinatorial Network Aware Cases being Addressed (Cont.)

- The same timing cases seen on the previous slide must be considered in the context of one NA component (C1) and one non-NA component (C2)
  - C1 occurring in a time relation case previously discussed while sharing resources in common may potentially create vulnerabilities.
    - E.g. A NA control application and a printer
  - Non NA components (application pieces) may have been justifiably engineered with little or no consideration of network security issues
  - A non-NA component may represent a piece of a NA application that does not interact with a network.
    - I.E. $t(X+n) < t(y), t(x) > t(y+m)$

Model Checking: A Case Study
Simplified State Machine for Prime



"Validating Requirements for Fault Tolerant Systems Using Model Checking", Schneider, Callahan & Easterbrook, 1998

This Case Study was funded by the NASA Software Program at the NASA IV&V Facility and JPL under a separate task

Real Project Application

- **JPL Class A Flight Project**
  - **Will test toolset on Flight Mission internet-aware communication software**
- **IsoWAN & Information Power Grid testbeds**
  - **Isolated wide-area networks using a modified VPN solution to create a secure, isolated, computing environment**
  - **Use with high-performance supercomputing collaborative environment**

Potential Follow-On Work

- Training in use of security assessment tools in the software development and maintenance life-cycle
- Development of re-composable model sub-components
- Develop capability for easy storage and access of a library of common network security model components and past verification results
- Develop a programmer interface to assist users with generating properties for input into the tools

Potential Follow-On Work (cont.)

- **Enhancing and augmenting the toolset**
  - Port the code to run on different operating systems
  - Include additional programming and scripting languages that the Tester's Assistant tool can slice for vulnerabilities
  - Augment the toolset by incorporating or developing additional tools
  - Develop a graphical user interface front-end checklist and decision tree to assist in building the Model to be verified

Collaborators

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  Network and Computer Security, JPL
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